Updated standardized CPUE of blue shark (*Prionace glauca*) in the Indian Ocean estimated from Japanese observer data between 1992 and 2016.

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Abstract

We updated the standardized CPUE of blue shark (*Prionace glauca*) based on the Japanese observer data, collected in the Indian Ocean between 1992 and 2016. We also modified the area stratification as well as model structures in the CPUE standardization. We compared four candidate models and we selected the zero-inflated negative binomial model as the most parsimonious model using AIC. The trends in the CPUE was increased in 1990s and reached to the peak in 1999 followed by sharp decline in 2000. After that the trend in the CPUE has been constant or slightly increasing with a large fluctuation.

1. Introduction

In the past analyses (Kanaiwa *et al*. 2014, Semba *et al*. 2015, and Semba and Kai 2016), the area of IOTC was divided into two subareas at the longitude of 90° E. This area stratification is adopted based on the distribution of effort for the longline vessels targeting for the southern blue fin tuna (*Thunnus maccoyii*) in the high latitude (Kanaiwa *et al*. 2014 and Semba *et al*. 2015). Given the situation that observer data in the tropical area has been collected and the distribution pattern of this species from tropical to subarctic waters, Semba and Kai (2016) analyzed the observer data from vessels which targets for not only southern blue fin tuna in the high latitude but also for tropical tunas such as bigeye tuna (*Thunnus obesus*) in the low latitude in the Indian Ocean. Recently, Coelho *et al*. (2017) estimated the distribution pattern by size for this population and suggested that larger blue sharks tend to occur in equatorial and tropical regions and smaller specimens in higher latitudes in temperate waters. In this context, we modified the subareas based on the predicted distribution pattern by size in the Indian Ocean by Coelho *et al*. (2017) and updated annual trend of standardized CPUE based on the revised model structure and the Japanese observer data, collected in the Indian Ocean between 1992 and 2016.

2. Materials and methods

1) Data set

We used the observer data compiled by Japan observer program, extracting the operation data collected in the Indian Ocean between 1992 and 2016. The data used for this analysis includes the number of catch of blue shark, the number of hooks, spatio-temporal information (year, month, latitude and longitude) of each operation and the number of branch lines between floats (hooks par basket: HPB).

2) Data filtering

We filtered the erroneous data using the same method with Semba *et al*. (2015) to remove the sets which have no information about latitude, longitude, hooks or HPB. We summarized the general information about the filtering data on the number of set, catch number, observed hook and nominal CPUE per year (Table 1).

3) Model description

We applied four generalized linear models (GLMs) to standardize the nominal CPUE. The models include (1) Poisson model (P), (2) negative binomial model (NB), (3) zero-inflated Poisson model (ZIP), and zero-inflated negative binomial model (ZINB). We used these GLMs except for NB in the past analyses (Semba *et al*. 2015, Semba and Kai 2016). We also modified the model structure, especially for the selection of the covariates, due to the different area stratification. We used the following four categorical variables;

1. Year: 1992 to 2016,
2. Season: 1 = April to July, 2 = August to December,
3. Area: Indian Ocean was divided into two latitudinal subareas (north and south at the latitude of 35°S),
4. Gear: shallow (HPB≤12) and deep (HPB>12),

We selected the covariates and interaction terms of the model using the outcome of ANOVA table which demonstrates whether the explanatory variable is statistically significant at 5% risk level. We used the same model structure for the count process of ZIP and ZINB as that used for Poisson and NB, however, we used only "year" as the covariate of the false zero probability for ZIP and ZINB to make it easy to converge. The model structure is as follows;

P and NB:

$$Catch = \alpha_1 * Year + \alpha_2 * Area + \alpha_3 * Season + \alpha_4 * Gear + \alpha_5 * Area : Gear + \alpha_6 * Area : Season + \alpha_7 * Season : Gear + intercept + \varepsilon$$

where $\alpha_1 \sim \alpha_7$ are coefficients for each factors and ε is error terms followed by Poisson distribution or negative binomial distribution. Logarithmic of number of hooks was used as offset term.

ZIP and ZINB:

$$Count\ process's\ catch = \beta_1 * Year + \beta_2 * Area + \beta_3 * Season + \beta_4 * Gear + \beta_5 * Area : Gear + \beta_6 * Area : Season + \beta_7 * Season : Gear + intercept + \varepsilon_1$$

$$False\ zero\ prob = \beta_8 * Year + intercept + \varepsilon_2$$

Here, $\beta_1 \sim \beta_8$ are coefficients for each factors and ε_1 is error terms followed by Poisson distribution or negative binomial distribution and ε_2 is error terms followed by binomial distribution. Link function of former and latter model is log and logit, respectively. Logarithmic of number of hooks was used as offset term for count process catch.

4) Model evaluation

We selected the best model from four candidate models using AIC. We also estimated the 95% confidence interval of the standardized CPUE using bootstrapping with one thousand replicates. Further, we show the Pearson residuals for each categorical variables to evaluate the fitting of the model to the data.

3. Results and Discussion

In this analysis, we modified the area stratification and the entire area was divided into two subareas at the latitude of 35°S, based on the recent study on the distribution pattern by size for this population and different type of targeting in Japanese tuna longline fishery in this area. According to Coelho *et al*. (2017), larger blue sharks tend to occur in equatorial and tropical regions where Japanese fleet mainly targets for tropical tuna with deep set (HPB>12) and smaller specimens in higher latitudes where Japanese fleet mainly targets for southern bluefin tuna with HPB with shallow set (HPB≤12). The boundary of 35°S was adopted based on the estimation of distribution pattern by size in Coelho *et al*. (2017) and the amount of Japanese size data. Because the distribution of HPB is not discretely differentiated between subareas, the validity of this boundary and possible effect on the standardization would be one of the future work.

Taking the inclusion of two different type of longline operation in the dataset into account, we added the effect of Gear to the GLM analysis which was not considered in the past analyses. In our models, the effect of Gear was statistically significant ($p < 0.05$). For the season, we used the same category (i.e. two seasons) as used in the past analyses, mainly due to the small number of the observation between January and March and its effect on the interaction term. This limitation mainly comes from the fishing season of southern bluefin tuna (SBT) and observation in SBT fishery still accounts for more than half of the data (average sets for all years account for 85%). Regarding the interaction term, interaction between year and season was significant in Poisson and NB, however, inclusion of this interaction term in the model not allow for ZIP and ZINB to convergence. Thus, we didn’t include the interaction term in the analyses.

Zero-inflated Negative binomial was selected as the most parsimonious model by the lowest AIC (Table2). The model includes four covariates (year, area, season, and gear) and three interaction terms (area-gear, area-season, and gear-season). As shown in Fig.1, the ratio of zero catch is not particularly high and it fluctuated between 0 and 0.3 over the whole years. It was pointed out by Kanaiwa *et al*. (2014) that the zero-inflated model have an advantage over general GLMs such as P and NB when the zero catch ratio is low with its high fluctuation, however, the ZINB was unstable and caused the failure of conversion for some combinations of the factors. We added NB to this analysis to compare the trend in the scaled CPUE and the results suggested that there was a little difference in the trend between NB and ZINB (Fig.2). This may be partly because of low zero catch ratio and limited covariate in the modeling for false zero probability in ZINB.

The standardized CPUE based on ZINB indicates large spike in the 1999 as in the past analysis, but another spike estimated in 2009 was modified to less prominent in the current analysis (Fig.3). Generally, the trend of abundance from 1992 to 2004 is relatively similar between the past and current estimates, but the differences are more prominent afterwards, especially between 2005 and 2011. This corresponds to the increase of observer data with deep set in the tropical area after around 2003-2004. In the early period (around 1992-2002), most of the set observed is from high latitude with HPB≤12 and thus, slight difference of the trend between estimates in the early period may reflect the effect of modification of subareas rather than inclusion of the gear effect. It is suggested that the effect of subarea and inclusion of gear effect are prominent in the later period. Throughout the period analyzed, there is no continuous increasing or decreasing trend throughout the period (Fig. 4). Estimated abundance index with its CV and Pearson residuals for each categorical for ZINB are shown in Table 3 and Appendix Figs 1-4, respectively.

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Table 1. Summary of data used in the analysis.

year	catch number	observed hook	nominal CPUE
1992	2,549	1,310,404	1.945
1993	1,323	656,373	2.016
1994	1,981	986,045	2.009
1995	2,892	1,252,228	2.309
1996	4,227	1,039,342	4.067
1997	2,552	1,289,690	1.979
1998	2,724	731,948	3.722
1999	3,682	533,777	6.898
2000	1,655	395,313	4.187
2001	3,777	1,090,940	3.462
2002	2,334	639,711	3.649
2003	3,423	794,412	4.309
2004	2,922	1,221,501	2.392
2005	4,948	1,791,084	2.763
2006	4,853	2,033,907	2.386
2007	2,978	1,181,800	2.520
2008	1,033	361,499	2.858
2009	1,975	580,163	3.404
2010	743	589,901	1.260
2011	1,462	643,614	2.272
2012	1,738	537,239	3.235
2013	1,033	927,596	1.114
2014	3,184	1,755,809	1.813
2015	4,183	1,545,376	2.707
2016	1,055	484,099	2.179

Table 2. AIC values for four candidate models.

Poisson GLM	Negative binomial GLM	Zero-inflated Poisson GLM	Zero-inflated negative binomial
106810.72	54389.55	96092.17	54376.92

Table 3. Estimated standardized CPUE and its C.V. for blue shark from 1992 to 2016.

	Median of standardized CPUE	C. V.
1992	1.069	0.083
1993	1.037	0.099
1994	1.059	0.080
1995	1.331	0.076
1996	2.264	0.061
1997	1.084	0.076
1998	2.291	0.093
1999	4.029	0.083
2000	2.148	0.146
2001	1.958	0.085
2002	2.130	0.092
2003	2.405	0.058
2004	1.368	0.068
2005	1.535	0.062
2006	1.380	0.060
2007	1.763	0.078
2008	2.211	0.081
2009	3.091	0.089
2010	1.609	0.082
2011	1.819	0.095
2012	2.431	0.055
2013	1.316	0.087
2014	1.985	0.061
2015	2.643	0.060
2016	2.772	0.087

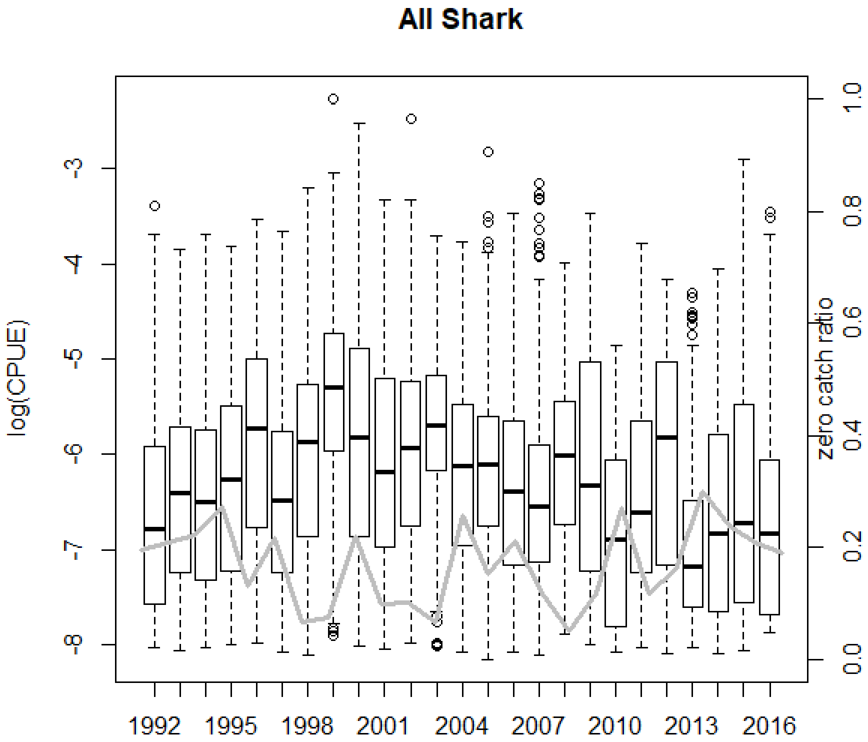


Fig 1. Annual trend of zero catch ratio (grey line and right y-axis) and nominal CPUE for positive catch (box plot: log scale, n / hooks; left y-axis) of blue shark from 1992 to 2016.

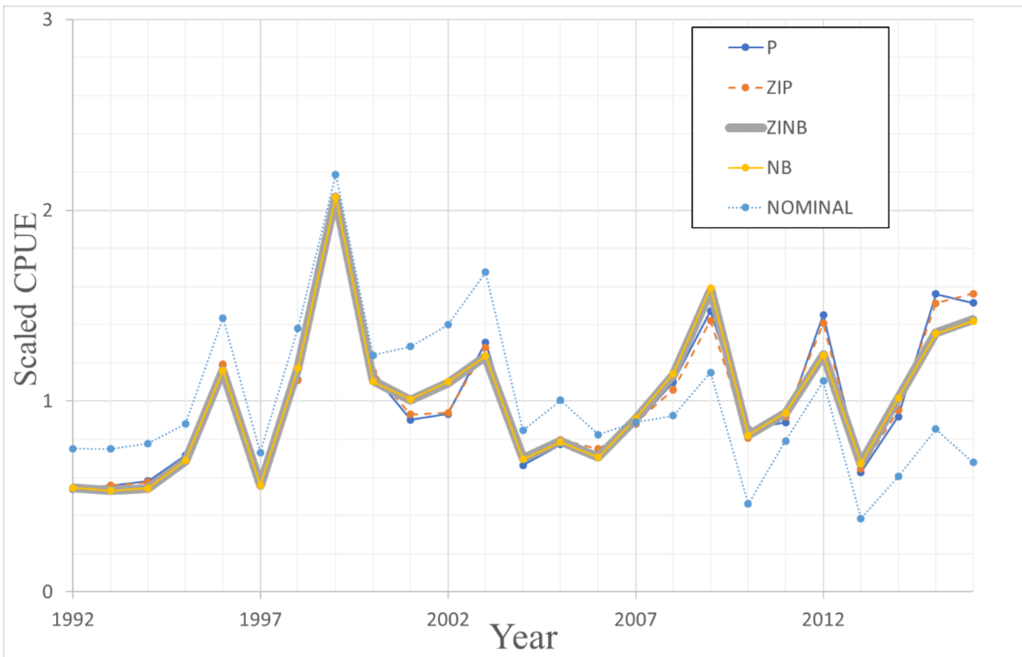


Fig.2 Compasiron of estimates of normalized CPUE of blue shark (after standardization) among four models.

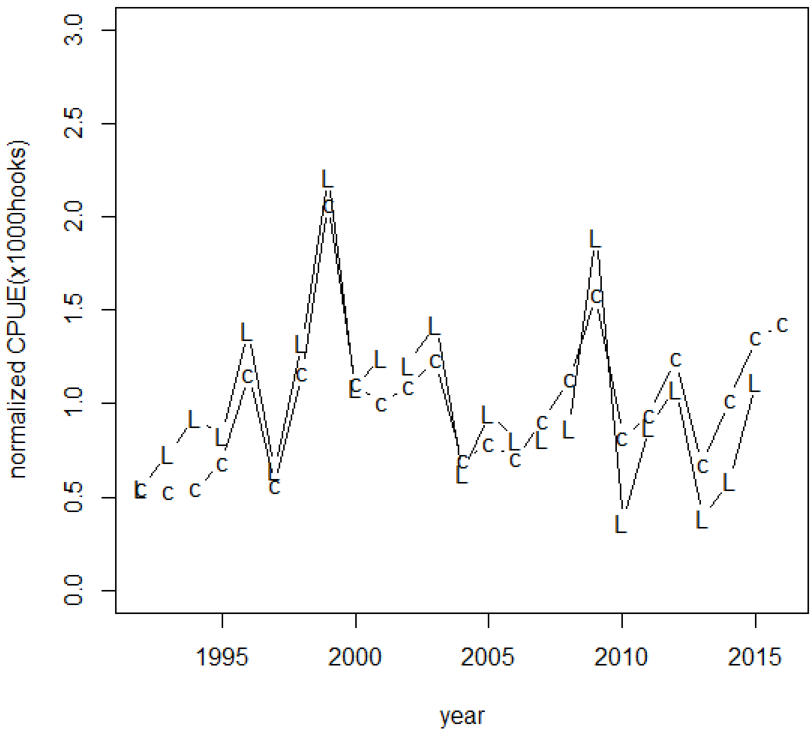


Fig.3 Compasiron of standardized CPUE of blue shark between past (“L” from Semba and Kai (2016)) and current (“c”) analysis.

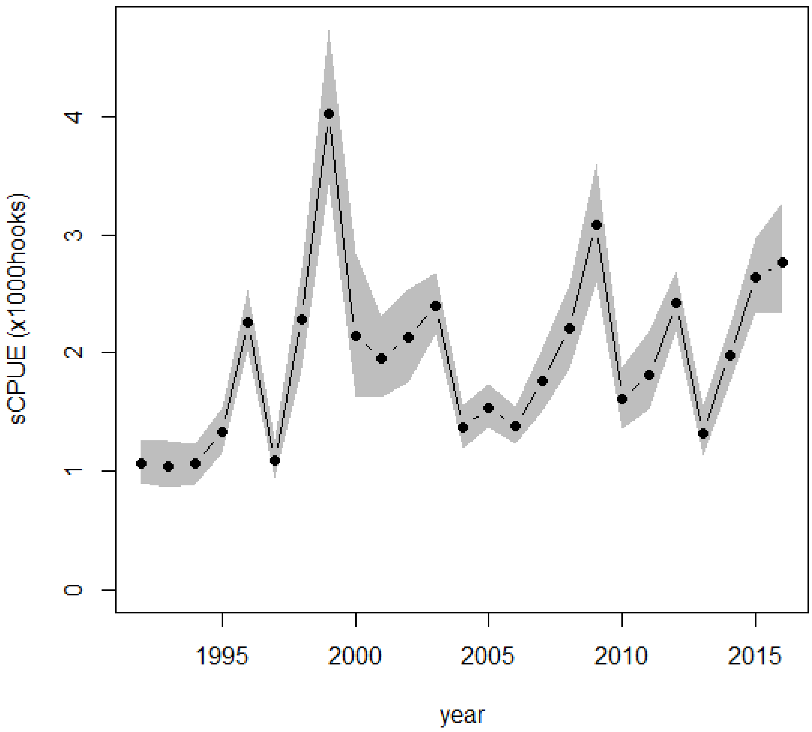
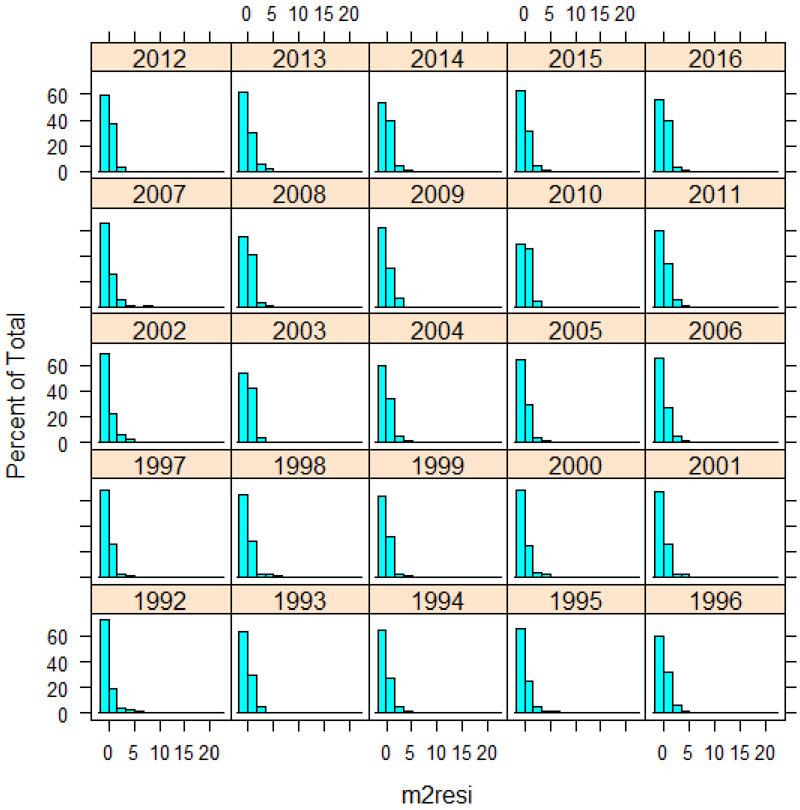


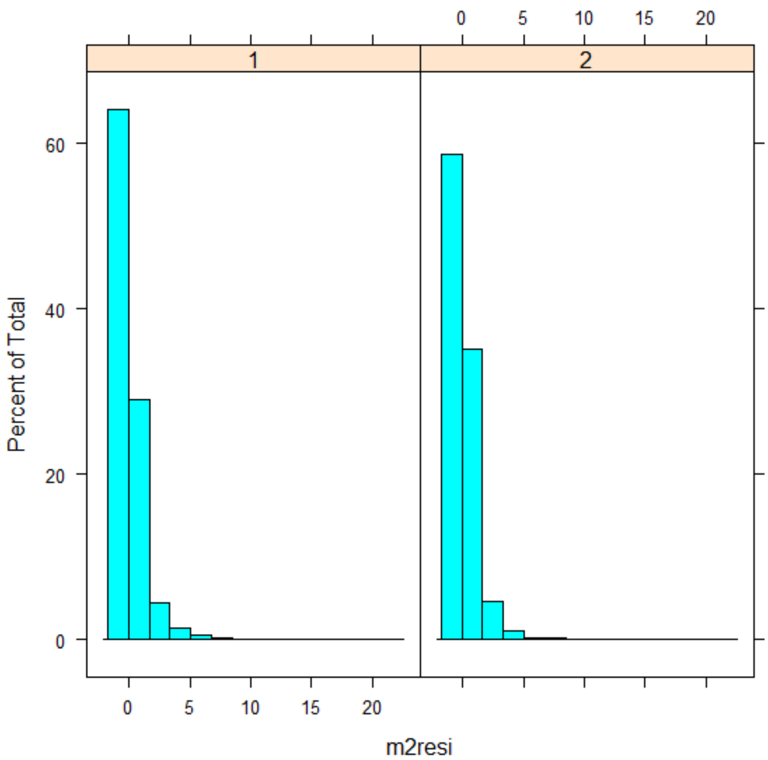
Fig. 4 Yearly changes in the standardized CPUE (black circle and solid line) with 95 % confidence interval (grey

shade). The CPUE was estimated from ZINB and the bootstrapping was conducted with one thousand replicates.

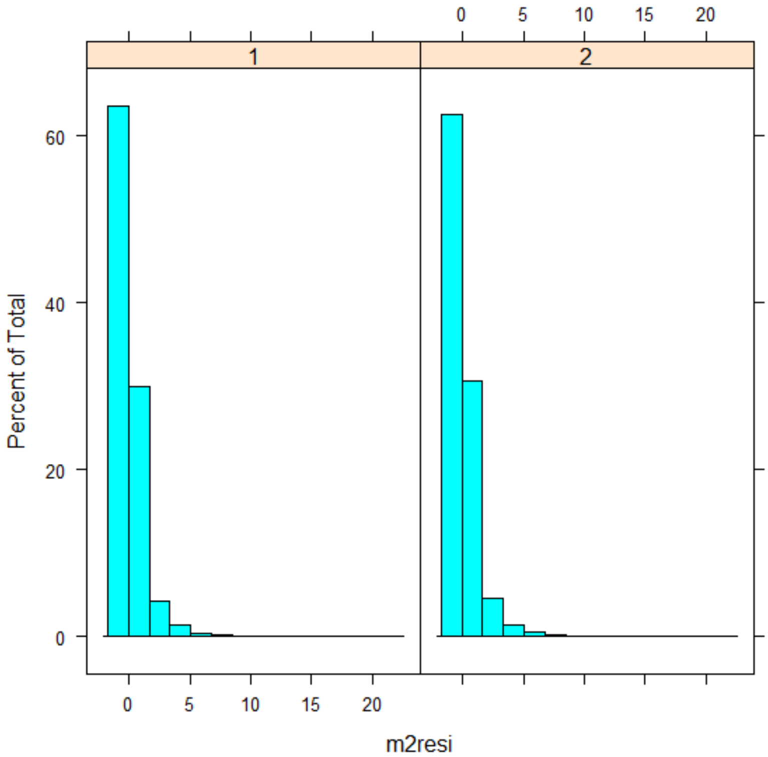
Appendix



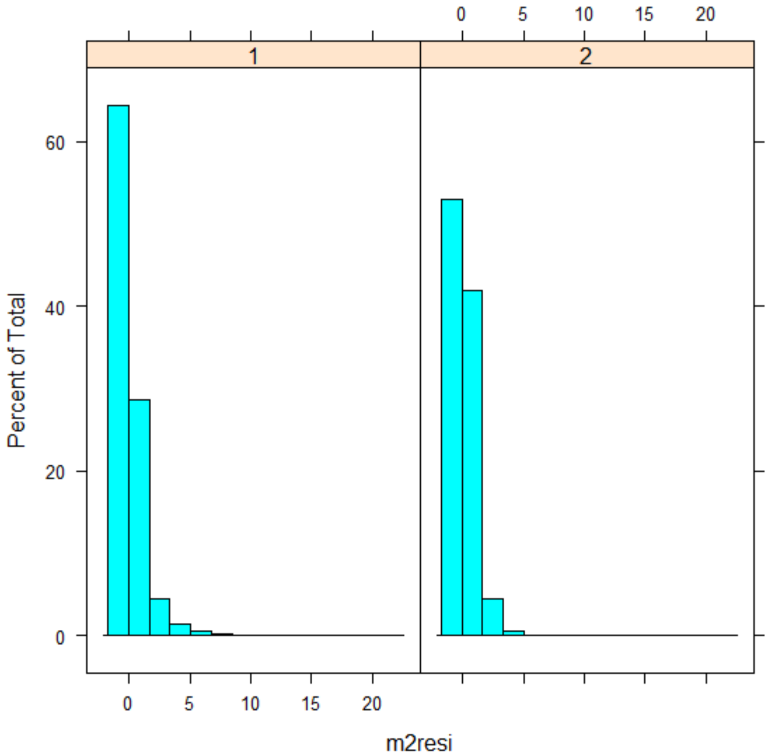
Appendix Fig.1 Annual residuals pattern for standardized CPUE of blue shark based on the observer data for Japanese tuna longline fishery operated in the Indian Ocean.



Appendix Fig.2 Area specific residuals pattern of analysis of CPUE of blue shark based on the observer data for Japanese tuna longline fishery operated in the Indian Ocean. In this panel, left graph shows pattern of area 1 (south of 35°S) and right is area 2 (north of 35°S).



Appendix Fig.3. Season specific residuals pattern of analysis of CPUE of blue shark based on the observer data for Japanese tuna longline fishery operated in the Indian Ocean. In this panel, left graph shows pattern of season 1 (April-July) and right is season 2 (August-December).



Appendix Fig.4. Gear specific residuals pattern of analysis of CPUE of blue shark based on the observer data for Japanese tuna longline fishery operated in the Indian Ocean. In this panel, left graph shows pattern of gear 1 (HPB≤12) and right is gear 2 (HPB>12).